*Clinical Journal of Sport Medicine,* 10:169–175


# Hip Abductor Weakness in Distance Runners with Iliotibial Band Syndrome

*Michael Fredericson, MD, *Curtis L. Cookingham, MS, PT, †Ajit M. Chaudhari, MS, *Brian C. Dowdell, MD, *Nina Oestreicher, BS, and ‡Shirley A. Sahrmann, PhD, PT

**Department of Functional Restoration, Division of Physical Medicine and Rehabilitation; †Biomotion Research Laboratory, Department of Mechanical Engineering, Stanford University, Stanford, California; and ‡Program in Physical Therapy, Washington University, St. Louis, Missouri, U.S.A.*

**Objective:** To examine hip abductor strength in long-distance runners with iliotibial band syndrome (ITBS), comparing their injured-limb strength to their nonaffected limb and to the limbs of a control group of healthy long-distance runners; and to determine whether correction of strength deficits in the hip abductors of the affected runners through a rehabilitation program correlates with a successful return to running.

**Design:** Case series.

**Setting:** Stanford University Sports Medicine Clinics.

**Participants:** 24 distance runners with ITBS (14 female, 10 male) were randomly selected from patients presenting to our Runners' Injury Clinic with history and physical examination findings typical for ITBS. The control group of 30 distance runners (14 females, 16 males) were randomly selected from the Stanford University Cross-Country and Track teams.

**Main Outcome Measures:** Group differences in hip abductor strength, as measured by torque generated, were analyzed using separate two-tailed *t*-tests between the injured limb, noninjured limb, and the noninjured limbs of the control group. Prerehabilitation hip abductor torque for the injured runners was then compared with postrehabilitation torque after a 6-week rehabilitation program.

**Results:** Hip abductor torque was measured with the Nicholas Manual Muscle Tester (kg), and normalized for differences in height and weight among subjects to units of percent body weight times height (%BWh). Average prerehabilitation hip abductor torque of the injured females was 7.82%BWh versus 9.82%BWh for their noninjured limb and 10.19%BWh for the control group of female runners. Average prerehabilitation hip abductor torque of the injured males was 6.86%BWh versus 8.62%BWh for their noninjured limb and 9.73%BWh for the control group of male runners. All prerehabilitation group differences were statistically significant at the $p < 0.05$ level. The injured runners were then enrolled in a 6-week standardized rehabilitation protocol with special attention directed to strengthening the gluteus medius. After rehabilitation, the females demonstrated an average increase in hip abductor torque of 34.9% in the injured limb, and the males an average increase of 51.4%. After 6 weeks of rehabilitation, 22 of 24 athletes were pain free with all exercises and able to return to running, and at 6-months follow-up there were no reports of recurrence.

**Conclusions:** Long distance runners with ITBS have weaker hip abduction strength in the affected leg compared with their unaffected leg and unaffected long-distance runners. Additionally, symptom improvement with a successful return to the preinjury training program parallels improvement in hip abductor strength.

**Key Words:** Running injuries—Overuse injury—Friction syndrome—Iliotibial band syndrome—Tensor fascia lata—Knee pain.

*Clin J Sport Med* 2000;10:169–175.

## INTRODUCTION

The majority of running injuries are related to the knee and most are due to the constant repetition of the running motion.[1] Iliotibial band syndrome (ITBS) is believed to result from the constant friction of the ITB sliding over the lateral femoral epicondyle. It is the most common cause of lateral knee pain in runners and accounts for 1.6 to 12% of all running-related injuries.[2–5]

Two studies of injury rates among runners found injury rates for ITBS of 2.1% and 4.7% of injuries, per 1,000 runners, per year.[6,7]

A biomechanical study that examined runners with ITBS noted that the posterior edge of the band impinges against the lateral epicondyle just after footstrike in the gait cycle. The friction occurs at, or slightly below, 30° of knee flexion.[8] This can produce irritation and subsequent inflammatory reaction, especially in the region beneath the posterior fibers of the ITB, which are felt to be tighter against the lateral femoral condyle than the anterior fibers.[4] The symptoms usually come on after a reproducible time or distance run and consist of a sharp pain or burning on the lateral aspect of the knee. Occasionally, there will be swelling and thickening of the tissue where the band moves over the lateral femoral condyle. Early on, the symptoms will subside shortly

Received May 27, 1999; accepted March 9, 2000.
Address correspondence and reprint requests to Michael Fredericson, MD, Department of Functional Restoration, Division of Physical Medicine & Rehabilitation, Stanford University Medical Center, Pasteur Dr., R-107B, Stanford, CA 94305-5105, U.S.A.

after a run is over, but will return with the next run. If allowed to progress the pain can persist even with daily walking and particularly when ascending and descending stairs.

Previous articles have suggested a number of etiological factors related to ITBS.[2–4] but they were all retrospective with no evidence of a temporal relationship between the risk factor and outcome. Messier et al.[9] found that runners with ITBS versus a noninjured control group were less experienced, were doing greater weekly mileage, and had a greater percentage of their training on the track. Additionally, the injured runners were weaker bilaterally in knee flexion and knee extension and exhibited lower maximal normalized braking forces. Factors postulated in other articles[2,3,4,10] such as training on crowned roads, varus alignment, excessive rear foot motion, and leg length discrepancies were not confirmed. One magnetic resonance imaging (MRI) study found that patients with ITBS have significantly thicker bands than controls without symptoms.[11]

Janda[12] has postulated a common muscle imbalance of weakness in the gluteus medius leading to early firing, overactivation, and tightness of the tensor fascia lata and iliotibial band. No previous study has examined for this muscle imbalance, particularly as it relates to ITBS in runners.

The hypothesis of this study is that distance runners with ITBS are weaker in their hip abductors on the injured limb versus their unaffected limb and the unaffected limbs of a control group of healthy distance runners. Additionally, correction of these deficits correlates with a successful rehabilitation program.

## METHODS

The treatment group for this study consisted of 24 consecutive collegiate and club long-distance runners who presented to our Runners' Injury Clinic for initial evaluation and were diagnosed with ITBS. Fourteen males and 10 females were chosen for the study, with an average age of 27.0 years (range 18–41). All were assessed by the principal author (M.F.) and had recent (within the last 2 months) symptoms and signs typical of ITBS. The prominent symptom in all runners was of lateral knee pain during running that gradually worsened. The diagnosis was confirmed by the presence of local tenderness over the lateral epicondyle, reproducible pain with flexion and extension of the knee while exerting pressure over the lateral femoral condyle with maximal pain at about 30° of knee flexion (Noble compression test), and the absence of any other signs in the knee joint proper, such as effusion, joint line tenderness, or a positive McMurray's test. Exclusion criteria included history of previous knee trauma, previous knee surgery, or symptoms on exam of other knee abnormalities including patellofemoral joint pain, popliteus tendinitis, lateral meniscal injury, or degenerative joint disease.

Any runner who had already been seen at another clinic and had received any form of supervised physical therapy was also excluded. We did not exclude runners who were performing nonsupervised stretching or strengthening exercises or who were already using ice massage or were taking nonsteroidal antiinflammatory drugs (NSAIDs).

The control group of 30 distance runners (14 female, 16 male) subjects were all Stanford University cross-country and track runners who were randomly selected to participate in this study during their preseason physicals in the summer and fall of 1995 and 1996. One leg was randomly chosen from each control subject to be included in the study. Table 1 shows comparison data for age, gender, height, and weight between the injured and control groups. All athletes participated on a volunteer basis. Data collected by interview included any history of previous or ongoing injury and subsequent rehabilitation. Exclusion criteria included any ongoing spine, hip, or lower extremity injury. Additionally, subjects were excluded if they had a history of previous lower extremity injury in the preceding 5 years that was not treated with a supervised physical therapy program until they were pain free and had returned to their sport.

For both the injured athletes and the control group, weight and height were self reported. Absolute leg lengths were measured by the interviewer by having the athlete lie supine on the examining table and measuring the distance from the anterior superior iliac spine to the highest point of the medial malleolus, bilaterally.[13]

Hip abductor strength was then measured by a team of two examiners, with one performing the physical test and the other recording the data. Test positions were as described by Kendall et al.[13] Strength was measured using a hand-held dynamometer (HHD).

Marino et al.,[14] using an HHD similar to the one used in this study, found that the dynamometer was able to detect even minor differences in muscle strength for the hip abductors and hip flexors that cannot readily be detected by the manual method of muscle testing. As rec-

**TABLE 1.** *Characteristics of study population*

| | | | Age (y) | | Height (m) | | Weight (kg) | |
|---|---|---|---|---|---|---|---|---|
| | | n | Mean | 95% CI | Mean | 95% CI | Mean | 95% CI |
| Females | Injured | 10 | 27.60 | 3.66 | 1.67 | 0.06 | 58.73 | 4.02 |
| | Controls | 14 | 19.71 | 0.65 | 1.70 | 0.03 | 56.92 | 3.97 |
| Males | Injured | 14 | 27.07 | 4.00 | 1.78 | 0.03 | 71.85 | 2.69 |
| | Controls | 16 | 20.06 | 0.66 | 1.80 | 0.04 | 66.28 | 2.49 |

CI, confidence intervals.

ommended in other studies, measurements from several trials were averaged to obtain a more true reflection of the mean muscle strength.[15,16] By allowing ample recovery time between trials, this method also avoided testing errors due to patient effort or measurement technique.

The HHD in this study measured the maximum static force on digital display. The instrument used was the Nicholas Manual Muscle Tester (MMT), manufactured by Lafayette Instruments (Lafayette, IN, U.S.A.). It measures static force from 0–199.9 kg, with reported accuracy to 0.1 kg ±2%.[14,17] The device uses a load cell force detecting system instead of a spring or hydraulic system. Load cell force systems tend to fatigue less easily with repetitive use than spring systems, and do not depend as heavily on calibration for their accuracy[18] (nevertheless, the HHDs were calibrated prior to each test session). The Nicholas MMT has also been shown to move less at the input shaft during testing than the spring system. It is limited by the strength of the examiner, as the strength of the examinee must be overcome by the examiner. However, in testing the hip abductors in this study all subjects were easily overcome. Additionally, it has a response time of 2 ms, which overcomes any potential errors in the examiner's perception of time required to apply the breaking force, and has a force platform that prevents errors in eccentric loading resulting from nonperpendicular force transmitted through the measuring apparatus.[14]

**Strength Test for Hip Abduction**

The subject was placed in a side-lying position on the examining table, with the shoulders and pelvis perpendicular to the table (Figure 1). The bottom leg was flexed and the upper arm grasped the examining table (both done to stabilize the trunk). The top leg was in alignment with the rest of the trunk. The patient was asked to abduct the leg toward the ceiling. Instructions were given to avoid any internal rotation or flexion of the hip through recruitment of the tensor fascia lata or any hip hiking through use of the quadratus lumborum.

Following a verbal description of test procedures, the examiner stabilized the dynamometer against the subject's leg just above the lateral malleolus, and at least two submaximal contractions and one maximal contraction were completed as practice prior to data acquisition. Following 30 seconds of rest, the subjects were instructed to hold their hip abducted at 30° isometrically. Maximum resistance was measured by the HHD as the force required to break the isometric contraction and bring the leg down to the table. Five trials were performed on each leg. A time period of at least 15 seconds was given between trials if the subject complained of any leg cramping. To maintain uniformity in tester–subject interaction, no encouragement was given to the subjects during the test.

Hip abductor strength was normalized for body weight and height.[19] The dynamometer measurement in kilograms was converted to Newtons [kg × 9.81] to achieve a unit of force. Newtons were then converted to torque [force (N) × action length (m)]. The measured leg length was used as the action length. Although the anterior superior iliac spine is not the center of the hip axis, because we scaled for differences in height this substitution did not significantly affect the data. The following formula was used to calculate a dimensionless measure of torque:

$$\% \text{ (BW} \times \text{h)} = \text{Torque (N} \times \text{m)} \times 100/\text{BW(N)} \times \text{h(m)}$$

Where BW is the subject's body weight in Newtons and h is the height in meters. Two examiners performed all of the strength measurements. Both legs of 10 additional noninjured control subjects were analyzed during the same session to determine interexaminer reliability. The strength testing was performed as described above with three trials averaged. To allow full recovery, 10 minutes was given between the tests performed by the two examiners.

Several studies have examined intrarater and interrater reliability of muscle testing with the HHD using Pearson correlation coefficients. Bohannon et al.[18] tested 18 ex-

**FIG. 1.** Hip abductor strength test.

tremities, with 3 strength tests per extremity. Intrarater reliability was shown to be greater than or equal to 0.97 in the majority of correlations. Hyde et al.[20] demonstrated test–retest reliability in two boys with muscular dystropy, with correlation coefficients of 0.94 for hip flexion, 0.86 for hip abduction, and 0.97 for knee flexion using the HHD. Another study by Bohannon[21] tested 6 muscle groups in 30 subjects, using 2 examiners. They found interrater reliability correlations of 0.84 for hip flexion and knee extension, 0.88 for shoulder external rotation, and 0.94 for wrist extension and elbow flexion.[21] Our interrater reliability measurements are in line with this previous research, with a 0.92 Pearson correlation coefficient between examiners. In addition, an intraclass correlation coefficient (ICC) was calculated[22,23] to assess interrater reliability using a two-way analysis of variance (ANOVA). Using this method, the ICC was 0.96, which compares favorably to other studies using the ICC.[23]

Validity assessment of the Nicholas HHD has been compared with isokinetic testing for shoulder abduction[24] and hamstring[23] strength testing with correlation coefficients of 0.83 to 0.86. We are unaware of any study in the literature, however, that has specifically compared HHD versus isokinetic testing for hip abductor strength.

### Rehabilitation

All injured runners were enrolled in a 6-week standardized rehabilitation program, with sessions scheduled once per week for 6 weeks. All patients were treated by the same physical therapist. Nonsteroidal antiinflammatory drugs were prescribed until the patients were pain free with daily activities. The therapy protocol consisted of local application of ultrasound with corticosteroid gel to decrease inflammation for the first one or two sessions. All patients were instructed in two standard stretches for the ITB to be performed three times per day, holding each stretch for 15 seconds (Figures 2 and 3). Side-lying hip abduction exercises and pelvic drops to strengthen the gluteus medius were started at 1 set of 15 repetitions and over a course of several weeks increased to the goal of 3 sets of 30 repetitions. The patients were instructed to increase by five repetitions per day provided there was no significant post work-out soreness the following day. For the side-lying hip abduction, specific instructions were given to keep the lower leg flexed for balance, the abdominals braced, and the upper leg in slight hip extension and external rotation. Instructions ensured that the leg was slowly brought into an arc of abduction of 20–30° with each repetition, held for 1 second at extremes of motion (Figure 4A), and then slowly returned to adduction (Figure 4B). The pelvic drop exercise involved standing on a step with the involved leg, while holding onto a wall or stick if necessary for support (Figure 5A). With both knees locked, the opposite, noninvolved pelvis was lowered towards the floor, shifting one's body weight to the inside part of the foot and involved leg, creating a swivel action at the hip (Figure 5B). Then, by contracting the gluteus medius on the involved side, the pelvis was brought back to a level position. A mirror was used during the initial stages to provide visual feedback until the exercise was performed correctly.

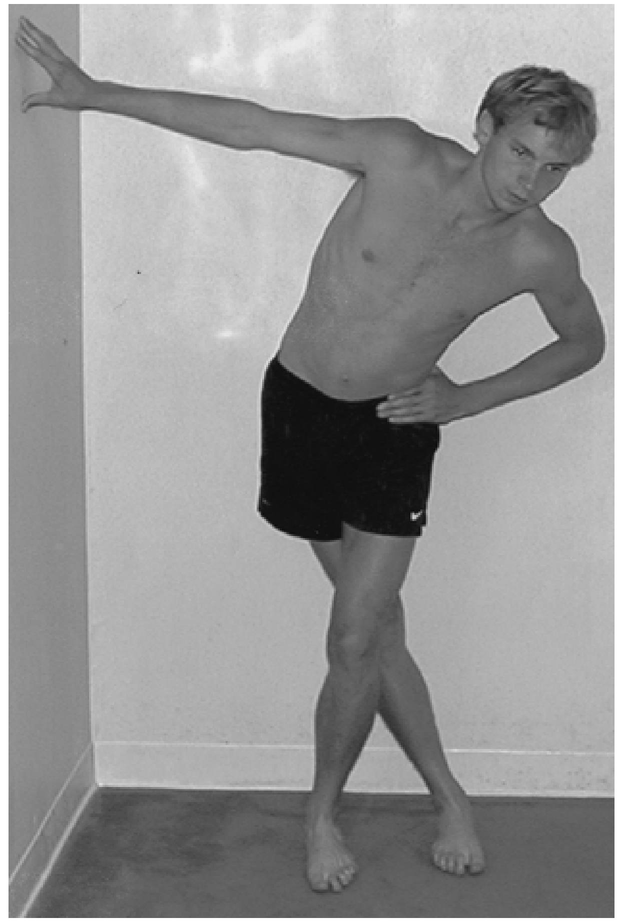
**FIG. 2.** Iliotibial band standing stretch.

All subjects were instructed to discontinue running and any other activities that continued to cause pain. Cross-training was allowed provided there was no provocation of pain during the exercise or post work-out. Subjects needed to be pain free with all daily activities and have progressed to 3 sets of 30 repetitions of the 2 strength exercises before being allowed to start a return to running program at the end of the 6-week rehabilitation program.

## RESULTS

Group differences in hip abductor strength were analyzed using two-tailed $t$-tests between the injured limb, noninjured limb, and the noninjured limbs of the control group. To compare the injured limb with the noninjured limb and to compare the injured limb before and after rehabilitation, paired $t$-tests were performed, while two-sample unequal-variance $t$-tests were performed to compare study patients with controls.

Figure 6 shows that the average prerehabilitation hip

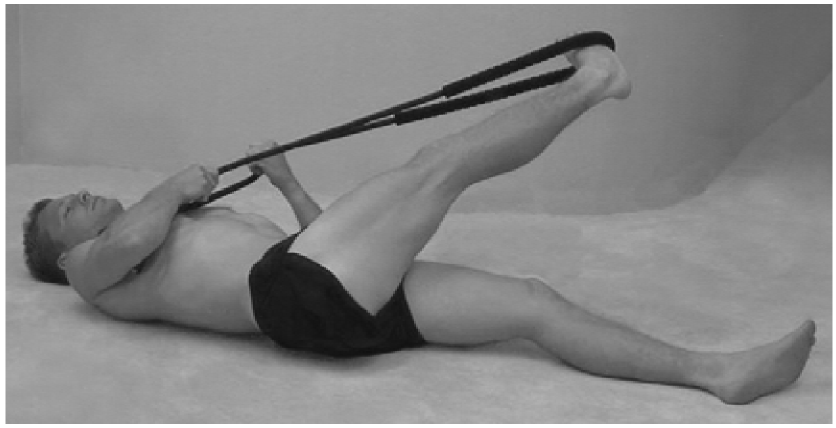

**FIG. 3.** Iliotibial band rope stretch.

abductor torque generated by the injured leg for the female study patients was 7.82 ± 1.93%BWh (95% confidence interval) versus an average of 9.82 ± 2.98 in the noninjured limb and 10.19 ± 1.10 in the control group female runners. The average prerehabilitation hip abductor torque generated by the injured leg for the male study patients was 6.86 ± 1.19 versus an average of 8.62 ± 1.16 in the noninjured limb and 9.73 ± 1.30 among the control group of male runners.

Figure 7 illustrates that for injured female runners, postrehabilitation there was an increase in average hip abductor torque to 10.55%BWh, a 34.9% increase. For injured male runners postrehabilitation, there was an increase in average hip abductor torque to 10.38, a 51.4% increase.

All comparisons were statistically significant at the $p < 0.05$ level.

At 6 weeks, 22 of 24 athletes were pain free and had started a return to running protocol; follow-up by phone at 6 months found no recurrences of ITBS. Of the remaining two runners, one required three months of rehabilitation and then began a very gradual return to running, while the other continued to suffer and decided to give up running.

## DISCUSSION

Since Bender's 1964 study[25] of 806 West Point cadets it has been known that those with strength differences greater than 10% between the limbs, and those in the


**FIG. 4.** Side-lying hip abduction exercise. **A:** Start position; **B:** end position.

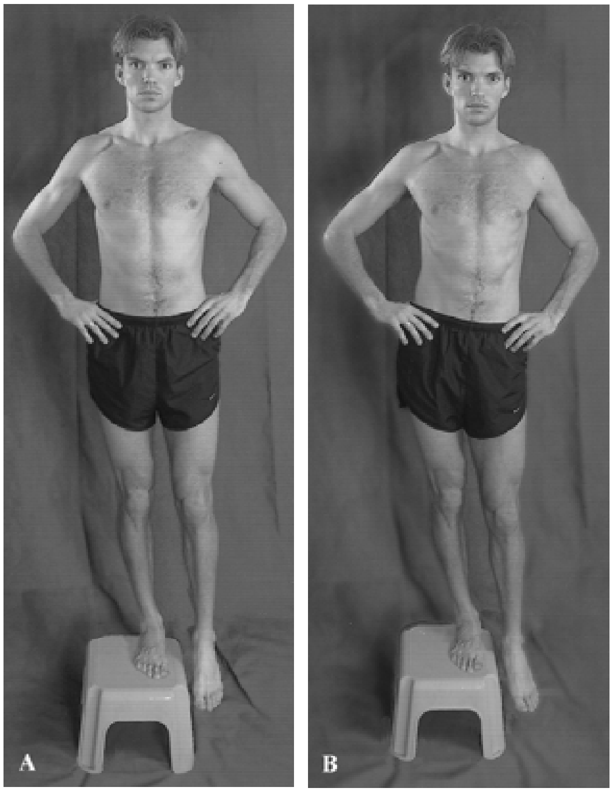


**FIG. 5.** Pelvic drop exercise. **A:** Start position; **B:** end position.

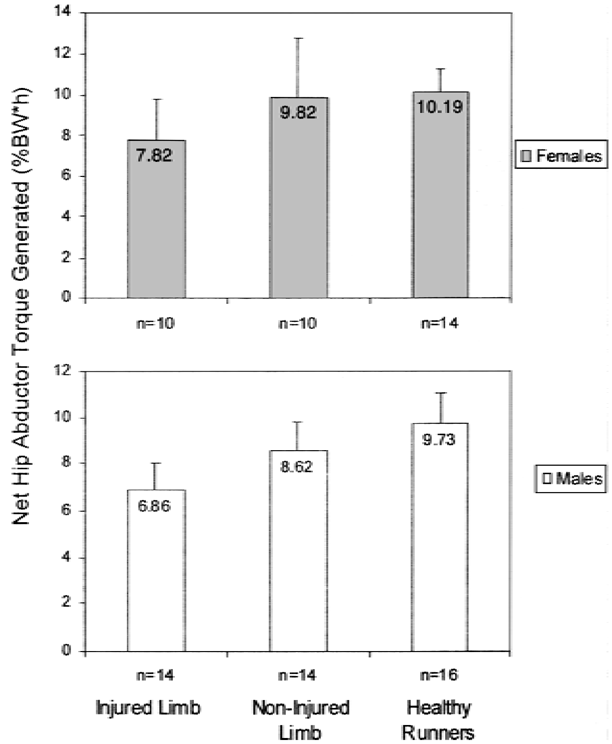


**FIG. 6.** Hip abductor torque before rehabilitation. Error bars represent 95% confidence intervals. All differences between groupings are significant ($p < 0.05$).

lowest quartile strength-wise compared with their peers, are more likely to be injured than those with normal strength levels. This study only examined isometric strength and only examined muscles in close proximity to the site of injury. It has also been shown that distal injuries produce more weakness to the entire limb than proximal ones. Nicholas et al.[17] in a retrospective study found that patients with ankle and foot problems had consistent weakness in their hip abductors and adductors as measured by Cybex testing. Previous work by Messier[9] also retrospectively found that in patients with ITBS there were deficits in knee flexor and extensor strength. Van Mechelen et al.[26] did do a prospective study of strength as a risk factor for injury by measuring isokinetic strength of the knee flexors and extensors using Cybex testing. They did not find a significant relationship between these strength variables and injury, but they did not specifically examine running injuries or hip abductor strength. No study has previously examined the relationship of more proximal weakness in the hip abductors and ITBS.

This study demonstrates that runners with ITBS were weaker in hip abductor strength than a noninjured control group of runners in comparison with their noninjured side. In both males and females, after 6 weeks of physical therapy strength for the injured limb achieved a level equal to or greater than that of the noninjured limb and control limbs.

It is not clear why distance runners are more prone to weakness in the hip abductors and ITBS. One possibility is that running is primarily a sagittal plane activity, whereas sports such as soccer require greater coronal plane movement, engaging the hip abductors more rigorously.

Electromyographic studies of joggers[27] have shown that in order to control coronal plane motion during stance phase, a continuous hip abductor moment is needed by the gluteus medius, and to a lesser extent the tensor fascia. These muscles demonstrate little change as the speed of gait increases. At the time of foot contact, the femur in relation to the pelvis is adducted; these muscles undergo an eccentric contraction, and then con-

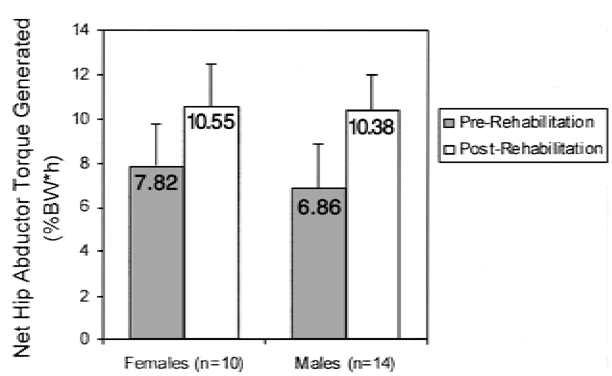


**FIG. 7.** Hip abductor torque of injured runners before and after rehabilitation. Error bars represent 95% confidence intervals. The differences between strength before and after were statistically significant ($p < 0.05$) for both men and women.

tract concentrically throughout the remainder of the support phase and into the propulsive phase as abduction occurs at the hip joint. While the gluteus medius and tensor fascia lata are both hip abductors, the gluteus medius (especially the posterior aspect) is an external rotator of the hip, whereas the tensor fascia lata is an internal rotator of the hip.[28] It is felt that weakness in the gluteus medius leads to decreased control of thigh abduction and external rotation. Subsequently, the runner will demonstrate increased thigh adduction and internal rotation with an increased valgus vector at the knee. It is postulated that this places the iliotibial band under increased tension and makes it more prone to impingement upon the lateral epicondyle of the femur, especially during the early stance phase of gait (foot contact) when maximal deceleration occurs to absorb ground reaction forces.

## LIMITATIONS

There was no true control group for the rehabilitation aspect of this study. The injured runners were compared prerehabilitation versus postrehabilitation for improvement in hip abductor strength. The ideal would have been to include a group of comparable long-distance runners also diagnosed with ITBS who did not receive a hip abductor rehabilitation program. The rehabilitation program included modalities, rest, stretching, and strengthening, and it is not clear that the strengthening program alone led to increases in strength and successful return to the running program. It is possible that simply eliminating the pain or normalizing tight soft tissues led to increased facilitation of the hip abductors. A prospective study is also needed to determine if runners with weakness in their hip abductors are at greater risk for developing ITBS and if these runners can decrease their risk by prophylactically strengthening their hip abductors.

## CONCLUSIONS

This study found that long-distance runners with ITBS have weaker hip abduction strength in the affected leg compared with the unaffected leg and unaffected long-distance runners. Additionally, symptom improvement with a successful return to the preinjury training program parallels improvement in hip abductor strength.

## REFERENCES


1. Van Mechelen W. Running injuries: a review of the epidemiologic literature. *Sports Med* 1992;14:320–335.
2. Barber FA, Sutker AN. Iliotibial band syndrome. *Sports Med* 1992; 14:144–148.
3. Linderburg G, Pinshaw R, Noakes TD. Iliotibial band syndrome in runners. *Phys Sportsmed* 1984;12:118–130.
4. Noble CA. Iliotibial band friction syndrome in runners. *Am J Sports Med* 1980;8:232–234.
5. Pinshaw R, Atlas V, Noakes TD. The nature and response to therapy of 196 consecutive injuries seen at a runner's clinic. *S Afr Med J* 1984;65:291–298.
6. Clement DB, Taunton JE. A guide to the prevention of running injuries. *Australian Family Phys* 1981;10:156–164.
7. Sutker AN, Barber FA, Jackson DW, et al. Iliotibial band syndrome in distance runners. *Sports Med* 1985;2:447–451.
8. Orchard JW, Fricker PA, Abud At, et al. Biomechanics of iliotibial band friction syndrome in runners. *Am J Sports Med* 1996;24:375–379.
9. Messier SP, Edwards DG, Martin DF, et al: Etiology of iliotibial band friction syndrome in distance runners. *Med Sci Sports Exer* 1995;27:951–960.
10. Schwellnus MP. Lower limb biomechanics in runners with the iliotibial band friction syndrome [Abstract]. *Med Sci Sports Exer* 1995;25:567 (S68).
11. Ekman EF, Pope T, Martin DF, et al. Magnetic resonance imaging of iliotibial band syndrome. *Am J Sports Med* 1994;22:851–854.
12. Janda V. *Muscle Function Testing*. London: Butterworths, 1983.
13. Kendall FP, McGreary EK, Provance PG. *Muscles: Testing and Function*, 4th ed. Baltimore: Williams & Wilkins, 1993.
14. Marino M, Nicholas JA, Gleim GW. The efficacy of manual assessment of muscle strength using a new device. *Am J Sports Med* 1982;10:360–364.
15. Bohannon RW. Measurement of muscle performance. *Postgrad Adv Phys Ther* 1988;2:1–24.
16. Whitley JD, Smith LE. Larger correlations obtained by using average rather than "best" strength scores. *Research Q* 1963;34:248–249.
17. Nicholas JA, Strizak AM, Veras G. A study of thigh muscle weakness in different pathological states of the lower extremity. *Am J Sports Med* 1976;4:241–248.
18. Bohannon RW. Test-retest reliability of hand-held dynamometry during a single session of strength assessment. *Phys Ther* 1986; 66:206–209.
19. Andriacchi TP, Kramer GM, Landon GC. The biomechanics of running and knee injuries. In: Finerman G, ed. *American Academy of Orthopaedic Surgeons Symposium of Sports Medicine: The Knee*. St. Louis: CV Mosby, 1985;23–32.
20. Hyde SA, Scott CM, Goddard CM. The myometer: the development of a clinical tool. *Physiotherapy* 1983;69:424–427.
21. Bohannon RW, Andrews AW. Interrater reliability of hand-held dynamometry. *Phys Ther* 1987;67:931–933.
22. Baumgartner TA, Jackson AS. *Measurement for evaluation in Physical Education.* Boston: Houghton Mifflin, 1975;78–86.
23. Trudelle-Jackson E, Jackson AW, Frankowski CM, et al. Interdevice reliability and validity assessment of the Nicholas hand-held dynamometer. *J Orthopaedic Sports Phys Ther* 1994;20:302–304.
24. Magnusson PS, Gleim GW, Nicholas JA, et al. Subject variability of shoulder abduction strength testing. *AJSM* 1990;18:349–354.
25. Bender JA. *West Point Study*. 1964.
26. Van Mechelen W, Twisk J, Molendijk A, et al. Subject-related risk factors for sports injuries: a 1-yr prospective study in young adults. *Med Sci Sports Exer* 1996;28:1171–1179.
27. Mann RA, Moran GT, Dougherty SE. Comparative electomyography of the lower extremity in jogging, running, and sprinting. *Am J Sports Med* 1986;14:501–510.
28. Hollingshead WH, Jenkins DB. *Functional Anatomy of the Limbs and back*. Philadelphia: Saunders, 1982:265.